Predictability of Particle Trajectories in the Ocean

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Award #: N000149910049

LONG TERM GOALS

The long term goal of this grant is to determine optimal employment and Lagrangian data assimilation strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean with potential applications to ecological, search and rescue, and the floating mine problems.

OBJECTIVES

The specific scientific objective of the work done has been to determine the effectiveness of using in-situ Lagrangian measurements and data assimilation techniques in improving the prediction of particle trajectories. This has been done initially in the context of an ocean model (MICOM) and then using real oceanic drifter data representing both small scale (the Adriatic Sea) and large scale (tropical Pacific Ocean) motion.

APPROACH

The work is based primarily on simple probabilistic particle models and data assimilation strategies. It also involves the use of OGCMs and processing of oceanic data.

WORK COMPLETED

A new method has been developed to address the problem of prediction of Lagrangian trajectories, considering the fact the Lagrangian data are especially suitable for practical applications since they move with the currents and can be easily released in situ. This method employs a simple data assimilation scheme to incorporate information from nearby buoys in order to estimate the turbulent flow characteristics and to improve the prediction of particle trajectories. This method has been initially developed in the context of an OGCM (MICOM), and the results are described in a paper (in press). Since it is portable, and it can easily be applied to real oceanic Lagrangian data as well. The work on a small scale application, using Lagrangian data from the Adriatic Sea is completed and the manuscript is submitted.

RESULTS

The main results, obtained in collaboration with other scientists, can be summarized as follows:

1) The predictability of particle trajectories in oceanic flows is investigated in the context of a primitive-equation, idealized, double-gyre ocean model. The original aspect of this study is the use of

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Predictability of Particle Trajectories in the Ocean**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Miami,Rosenstiel School of Marine and Atmospheric Science,4600 Rickenbacker Causeway,Miami,FL,33149**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Lagrangian drifter data to improve the accuracy of predicted trajectories. The prediction is performed by assimilating velocity data from the surrounding drifters into a Gauss-Markov model for particle motion. The assimilation is carried out using a simplified Kalman filter.

The performance of the prediction scheme is quantified as a function of a number of factors: (i) dynamically-different flow regimes: interior gyre, western boundary current and midlatitude jet regions; (ii) density of drifter data used in assimilation; and (iii) uncertainties in the knowledge of the mean flow field and the initial conditions. The simulations indicate that predictions improve significantly when the number of data per degrees of freedom, NR>1. Even when the mean flow field and initial turbulent velocities are not known accurately, the information derived from the surrounding drifter data is shown to compensate when NR>1. Theoretical error estimates are derived which are based on the main statistical parameters of the flow field. Theoretical formulae show good agreement with the numerical results and hence they may serve as useful a-priori estimates of Lagrangian prediction error for practical applications.

This work has been performed in collaboration with L. I. Piterbarg (U. Southern California).

2) To test the new prediction scheme with real drifter data, predictability of Lagrangian particle trajectories in the Adriatic Sea (a semi-enclosed sub-basin of the Mediterranean Sea) is investigated using three clusters consisting of 5-7 drifters each over a period of 1-2 weeks. The results of this study (see Fig. 1 for a brief introduction) conducted with real drifter data confirm those with synthetic data that the assimilation of the drifters is efficient for NR > 1, while it does not improve the prediction for NR < 1. Also, when the mean flow is assumed unknown or an error in the initial position smaller than the Rossby radius of deformation is introduced, predictions are still in good agreement with observations.

This work has been performed in collaboration with P.-M. Poulain (NPS, Monterey).

3) To complement the OCGM and small-scale application (the Adriatic Sea) studies of the new method, we have also started to test it using WOCE drifter data in the tropical Pacific Ocean for large-scale applications. Several clusters of drifters have been tested, with results confirming those of previous studies, hence indicating the validity of our technique for flows for a wide range of scales. Several model improvements have been implemented, most importantly: i) generalization of the Kalman filtering technique for drifter positions and well as velocities; and ii) incorporation of the Coriolis acceleration in the equations of particle motion. This study also emphasizes the difference between estimating (theoretically) the prediction error for a cluster and for a uniformly distributed drifter ensemble (implemented in our previous study outlined in (1)).

This work is being performed in collaboration with L. I. Piterbarg (U. Southern California).

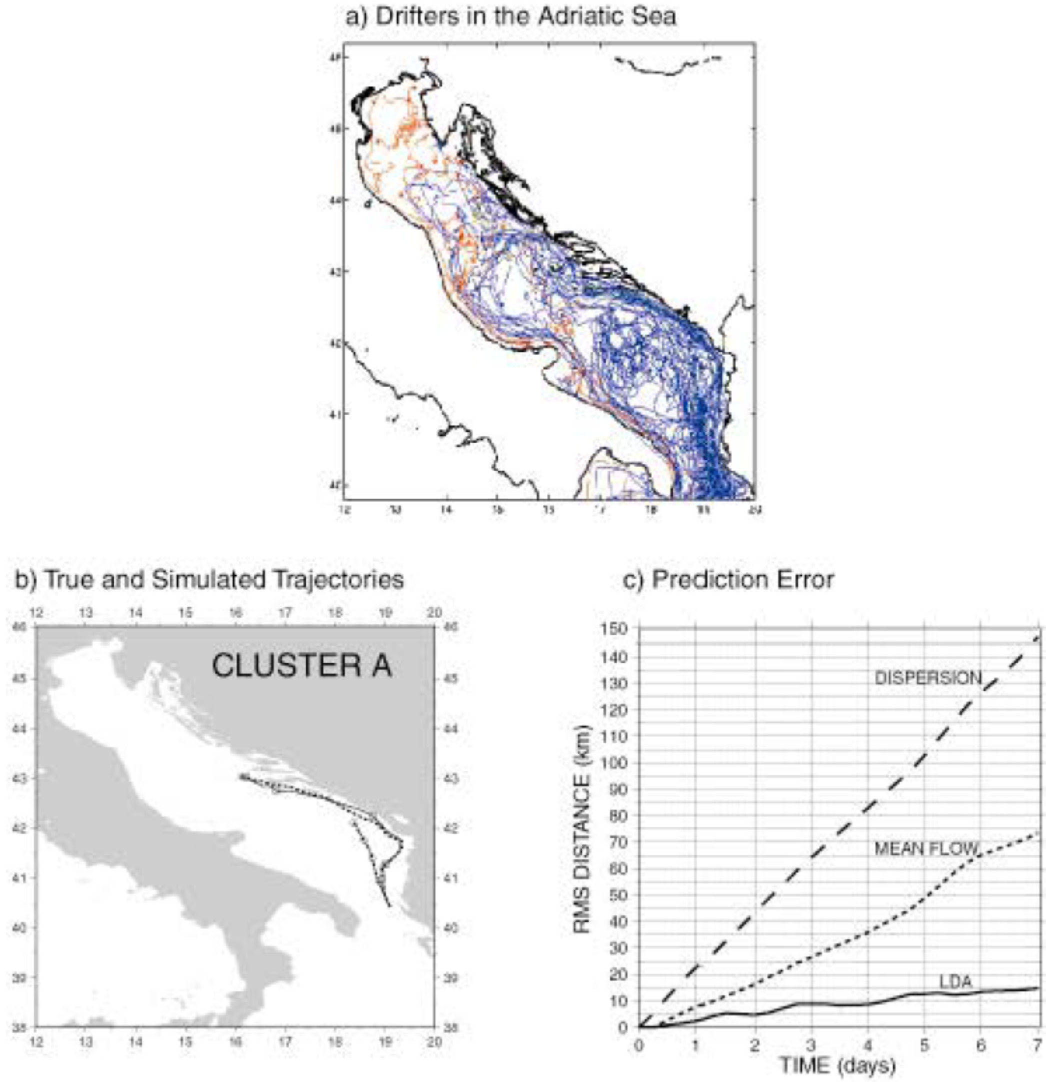

Figure 1: (a) Trajectories of drifter clusters released in the Adriatic Sea (Poulain, 1999). (b) True and simulated trajectories for drifter # 24098 from Castellari et al. (1999). Solid line indicates the true trajectory, simulated trajectory using only the mean flow information is shown with dashed-dotted line, and dashed line depicts the predicted trajectory using our model (11)-(12). Trajectories are marked at 5 day intervals. Similar results have been obtained for the other drifters in this cluster. (c) Absolute dispersion (average distance travelled) of particles, (long dashed line), rms prediction error using only the mean flow (short dashed line) and rms prediction error using the Lagrangian data assimilation model (solid line).

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, and estimating mass transport for climate studies.

TRANSITIONS

Theoretical work is ongoing with our close collaborator L. I. Piterbarg, for the clarification of the difference between the prediction error for a cluster and for a uniformly distributed drifter ensemble, and for the development of appropriate theoretical estimates for clusters.

Improvement of model dynamics is being planned. Considering the fact that for many of the practical applications of the project, the behavior of particles at the surface of the ocean is of importance, the incorporation of wind forcing into the governing equations for particle motion is being planned. A reapplication of the improved model to the Adriatic drifter data set will be conducted using the NORAPS wind data provided by P.-M. Poulain. We anticipate that P.-M. Poulain will be a close collaborator during this study, as he was in our previous Adriatic study.

Ensemble Kalman Filtering techniques are planned to be tested in collaboration with M. Chin (JPL).

Particle predictability study is planned for the drifter data set in the Caribbean Sea, in collaboration with K. Leaman (RSMAS).

RELATED PROJECTS

Lagrangian data analysis in mesoscale prediction and model validation studies. PIs: A. Griffa, T.M. Ozgokmen.

Statistical Problems in Ocean Modeling and Prediction. PI: L.I. Piterbarg.

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